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RESEARCH ARTICLE

Assessment of vanadium pollution and ecological risk in some selected waste dumpsites in Southeastern Nigeria

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Abstract: Waste disposal on dumpsites has resulted in significant vanadium pollution of the soil and ecosystem. This study assessed the pollution status and potential ecological risk of vanadium in some selected waste dumpsites in southeastern Nigeria. In this study, the soil samples were taken from the active waste dumpsites using a stainless-steel soil auger at a depth of 0 – 20 cm. Five sub-samples were taken from each sample location. A control sample was taken from an area devoid of industrial activities and waste dumps. Soil samples were air-dried at room temperature, pulverized with an agate mortar and pestle, and stored using appropriately labeled polythene bags prior to analysis. Vanadium analysis was conducted using an FS240AA atomic absorption spectrophotometer, and the data generated was analysed using IBM SPSS version 20.0 and Ms-Excel 2007. The mean vanadium concentrations in the studied waste dumpsites were found to be in the following order: Okpuno-Egbu dumpsite > Nekede dumpsite > Enyimba dumpsite > Rice-mill dumpsite. Acceptable potential ecological risk indices were observed in the Rice-mill, Enyimba, and Okpuno-Egbu dumpsites, while Nekede dumpsite recorded a high potential ecological risk. Furthermore, the pollution load index revealed that all the studied dumpsites were heavily polluted. Statistical analysis revealed no significant variations in vanadium concentrations in the studied dumpsites (p>0.05). Additionally, there was a strong and positive correlation between the dumpsites of Enyimba/Nnewi (r = 0.634), Nekede/Nnewi (r = 0.615), and Nekede/Rice-mill (r = 0.842); and thus indicated a similar source. The source of the vanadium pollution in the studied waste dumpsite soils was attributed to anthropogenic activities such as disposal of domestic and industrial wastes containing iron and steel.

Keywords: vanadium pollution, ecological risk, toxicity, waste dumpsite

1 Introduction

Vanadium (V) is an ubiquitous transition metal that is relatively abundant in nature [1]. It is essential for humans and other living species because of its roles in biological structures and functions [2,3]. Vanadium is found in a variety of oxidation states, including -1, 0, +2, +3, +4, and +5 [4,5]. However, vanadium pentaoxide (V_2O_5) is the most prevalent and widely used vanadium compound [6]. Moreover, pentavalent oxyanion vanadate, $H_2VO_4{}^{2-}$, is the most soluble specie that predominates under high pH conditions due to its mobility in soils often influenced by sorption to metal hydroxides [4,7,8]. According to Baken et al. [9], the mobility and bioavailability of vanadium are a function of time and soil properties. Also, the sorption properties of vanadium, as well as its redox chemistry, play a big role in its toxicity in soils [1]. Historically, vanadium (V) has been viewed as a conservative element in surface environments due to its great mobility. It exhibits multiple interactions at the surface, such as complexing with organic and inorganic substances in sediments and uptake into plants and animals, which could eventually reach humans if consumed [1,3,10]. Furthermore, vanadium (V) has represented a controversial problem in the soil from being a rare and unconcerned metal to becoming a major risk to the global environment due to its carcinogenic properties [12,13]. In addition, long-term exposure to V may exert toxic effects on the cardiovascular system, respiratory and digestive organs, kidneys, liver, skin and immune system of human beings [14,15].

In the past few decades, attention has been drawn towards vanadium due to its toxicological effects on humans, plants and animals, the different sources of pollution and the potential environmental impact [2,9,13–15]. Natural sources of vanadium contaminated soils are parent rocks [16]. However, anthropogenic activities such as combustion of fossil fuel, mining, fertilizer and pesticide application, and discarded iron and steel wastes on dumpsites have led to serious vanadium pollution in the soil and environment [2, 17, 18].

In Southeastern Nigeria, industrialization and urbanization have resulted in indiscriminate waste disposal due to the large volume of wastes generated in the production of irons and steels [2]. One common method of waste disposal is open dumping in waste dumpsites [19, 20]. This is a traditional method typically used in abandoned quarries, mining pits, or excavated pits that are located away from residential areas [19–23]. Industrial wastes from abandoned or malfunctioning vanadium-containing products such as iron and steel are disposed of in dumpsites, which, in effect, has led to the accumulation of vanadium in waste dumpsite soils [2, 6, 7, 9, 16]. Consequently, such waste dumpsites act as host for leachates, and constitute a cause of soil pollution [22, 24, 25].

In light of growing vanadium levels in soils and the environment, there is an urgent need to monitor its pollution and, subsequently, the ecological risk. Moreover, there is a paucity of knowledge about the degree of vanadium buildup in waste dumpsite soils. Previous studies have reported vanadium contamination in soils [1, 4, 6, 8, 9, 26]. However, very little has been documented about vanadium contamination in waste dumpsite soils and the potential ecological risks associated with its pollution. It is noteworthy to mention that vanadium has a strong attraction to organic materials, which often leads to its accumulation in organic-rich soils [11, 26, 27]. The purpose of this study was to fill this knowledge gap. Furthermore, statistical methods such as correlation analysis (CA) and ANOVA have been frequently utilized to investigate the accumulation and origin of metals in waste dumpsite soils [16, 28–30].

In this study, CA was used to confirm the degree of relationship between the vanadium concentrations in the studied waste dumpsite soils; whereas the significant differences in vanadium levels between the studied waste dumpsite soils were determined using ANOVA.

2 Materials and methods

2.1 Description of the study area

The study areas are Enyimba, Okpuno-Egbu, Rice-mill and Nekede waste dumpsites, which are located in Southeastern Nigeria. Enyimba waste dumpsite is located at Latitude 05°06.796′ N and Longitude 07°19.604′ E, the Okpuno-Egbu waste dumpsite is located at Latitude 6°00′40.88′′N and Longitude 6°54′26.87′′ E, the Rice-mill waste dumpsite is located at Latitude 6.3231° N and Longitude 8.1120° E, while the Nekede waste dumpsite is located at Latitude 5.485° N and Longitude 7.035° E (Figure 1). These waste dumpsites are very active and contain all kinds of waste, but mainly domestic, municipal, and industrial waste [20, 28]. The study area's climate is tropical wet, with two distinct seasons (rainy and dry), with annual rainfall ranging from 2500 – 4000 mm and daytime temperatures ranging from 18 to 34°C [31, 32]. Our earlier reports have given a detailed description of these dumpsites [19, 20].

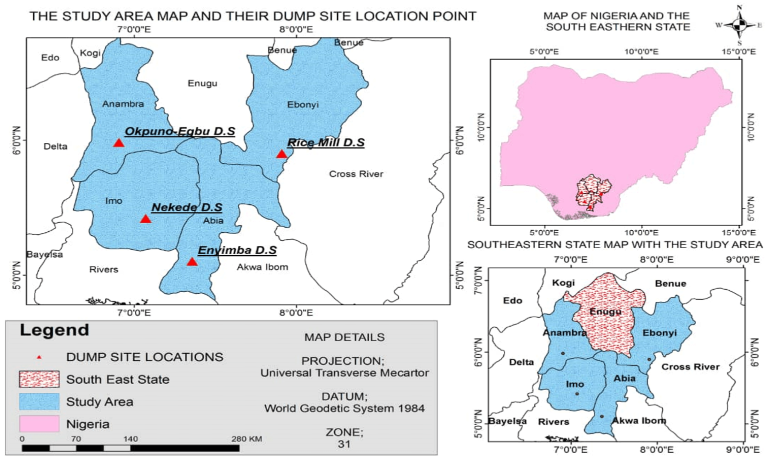

Figure 1 Study area map showing waste dumpsite locations in Southeastern Nigeria

2.2 Sample Collection and Preparation

At a depth of 0 – 20 cm, a stainless-steel hand auger was used to collect 80 soil samples from the selected active waste dumpsites. The soil samples were later pooled together to form composites. Due to the size of the studied waste dumpsites, they were divided into four sampling locations: east, west, north, and south, and five sub-samples were collected in each location. After soil sample at each waste dumpsite, the soil auger was cleaned with distilled water. A control sample was taken from an area devoid of industrial activities and waste dumps but underlain by similar geological units. At room temperature (21 – 27^{o}C), the soil samples were air-dried, pulverized with an agate mortar and pestle, sieved to fine particle sizes of about 0.75μm with a vibratory electronic sieve shaker to reduce soil matrix effects [28], stored in appropriately labeled polythene bags, and then ready for metal analysis. Soil samples were collected in February 2022, during the dry season to avoid metal leaching into the subsoil.

2.3 Metal analysis

The metal analysis was performed using an FS240AA atomic absorption spectrophotometer (AAS) in accordance with the Association of Analytical Chemists' recommended procedure, AOAC [33]. About 3.0 g of the prepared soil samples were digested for 3 hours with 15.0 ml HNO_3, 20.0 ml $HClO_4$, and 15.0 ml HF acid, on a hot plate. The digests were filtered into a 100.0 ml volumetric flask after cooling and brought up to the required volume with distilled water. The digested samples were analyzed for vanadium concentrations using the FS240AA AAS. The manufacturer's specifications were followed when setting up the device and operating it. A standard reference material (CRM 601) filter from the National Institute of Standards and Technology (NIST) was analyzed for metal concentration [35], and the results were compared to their certified values to validate the analyses; the results were found to be within 5% of the certified values [19, 20].

2.4 Data analysis

The IBM SPSS (statistical software for social sciences) version 20.0 and Ms-Excel 2007 were used to analyze the data in this study. Pearson's correlation matrix and analysis of variance (ANOVA) were used to establish a relationship between the soil vanadium concentrations at a 5% level of significance.

2.5 Calculation of potential ecological risk

The ecological risk index (ERI) developed by Hakanson [36] has been used by numerous researchers to quantify the ecological risk of metals in soils [19, 21]. In this study, the ERI was used to determine the extent of vanadium pollution in the studied waste dumpsite soils, and was calculated using equation 1.

Where TRF is the given vanadium toxic-response factor (i.e., V = 2.00), C_i represents the measured vanadium content in the soil, and C_o is the corresponding background vanadium concentration (control) [27, 37]. The potential ecological risk index (PERI) for each waste dumpsite is calculated by adding the individual potential risk factors. The potential ecological risk index (PERI) can be classified as low (40), moderate (40 – 80), significant (80 – 160), high (160 – 320), and very high (> 320) based on the obtained values [27, 36].

2.6 Calculation of vanadium pollution load indices (VPLI)

The individual pollutant load indexes were used to assess the overall contamination state of the waste dumpsites analyzed [22, 23]. This was also used to assess pollution levels between dumpsites in order to recommend appropriate action. In this study, the vanadium pollution load index (VPLI) at each waste dumpsite was obtained using Equations 2 and 3.

$$VPI = C_i / C_o \quad (2)$$

$$VPLI = (V1 + V2 + V3 + V4)^{1/4} \quad (3)$$

Where VPI represents the vanadium pollution index at each dumpsite, Ci is the measured vanadium concentration in the soil, and C_o is the corresponding background value (control) of vanadium concentration, VPLI represents the vanadium pollution load index, and V1, V2, V3 and V4 are the respective vanadium concentrations in locations east, west, north and south of the studied dumpsites, respectively. Based on VPLI values, vanadium pollution can be categorized as VPLI < 1 (No pollution), 1< VPLI < 2 (moderate pollution), 2< VPLI < 3 (heavy pollution), and 3< VPLI (extremely heavy pollution) [36–39].

3 Results and Discussions

3.1 Concentration of vanadium in soils

The mean concentrations of vanadium in the studied waste dumpsite soil samples are represented in Table 1. Vanadium concentrations at the Enyimba dumpsite ranged from 20.00 mg

kg^{-1} to 92.00 mg kg^{-1}. In the Okpuno-Egbu dumpsite, vanadium (V) concentrations ranged from 36.00 mg kg^{-1} to 152.00 mg kg^{-1}. The vanadium concentrations in the Rice-mill and Nekede waste dumpsites, respectively, ranged from 43.00 mg kg^{-1} to 61.00 mg kg^{-1} and 5.00 mg kg^{-1} to 230.00 mg kg^{-1}. Generally, the reported vanadium concentrations in the waste dumpsites analyzed revealed no significant differences ($p>0.05$) and were relatively higher than the values reported by Guagliardi *et al.* [43] for urban soils in southern Italy. This was attributed to the adverse effects of anthropogenic activities within the studied waste dumpsites. According to Onwukeme and Eze [28], a p-value greater than 0.05 indicates that the waste dumpsite soil is independent of the effects of the metal.

Table 1 Concentrations (mg kg^{-1}) of vanadium in the waste dumpsites studied

Samples	Enyimba Dumpsite	Okpuno-Egbu Dumpsite	Rice-mill Dumpsite	Nekede Dumpsite
V– 1 (East)	64.00±4.31	134.00±18.25	43.00±10.11	29.00±7.07
V– 2 (West)	20.00±2.10	36.00±9.10	56.00±16.09	62.00±19.14
V– 3 (North)	92.00±10.22	152.00±19.33	61.00±11.17	230.00±20.39
V– 4 (South)	80.00±13.32	51.00±11.11	47.00±8.08	5.00±2.03
Control	8.00±1.05	11.00±2.04	5.00±1.52	3.00±1.01
Sum	256	373	207	326
Mean	64.00	93.25	51.75	81.50
S.D	31.50	58.24	8.22	101.72
Minimum	20.00	36.00	43.00	5.00
Maximum	92.00	152.00	61.00	230.00

3.2 Potential ecological risk indices

The mean ecological risk indices (ERI) of vanadium in the studied dumpsites ranged from 5.00 to 23.00 (Enyimba), 6.55 to 27.64 (Okpuno-Egbu), 17.20 to 24.40 (Rice-mill), and 3.33 to 153.33 (Nekede). Similarly, the potential ecological risk indices (PERI) which is the sum of the individual ecological risk factors in Enyimba, Okpuno-Egbu, Rice-mill, and Nekede dumpsites are 64.00, 67.82, 82.80, and 217.32 respectively (Table 2). It can be seen that Enyimba and Okpuno-Egbu dumpsites had a moderate PERI while Rice-mill dumpsite had a considerable PERI. However, the Nekede dumpsite recorded a high potential ecological risk. According to Mugoša et al. [38], high PERI values of heavy metals in the environment could cause significant health problems in humans. Furthermore, the PERI between the studied waste dumpsites is in the following order: Nekede dumpsite > Rice-mill dumpsite > Okpuno-Egbu dumpsite > Enyimba dumpsite.

Table 2 Toxicity response factor, potential ecological risk index (PERI) and pollution load index (PLI) of vanadium in the studied waste dumpsites

Waste Dumpsites	Toxicity Response Factor	Potential Ecological Risk Index	Pollution Load Index
Enyimba	2	64	2.38
Okpuno-Egbu	2	67.82	2.41
Rice-mill	2	82.8	2.54
Nekede	2	217.33	3.23

3.3 Pollution load indices (PLI)

The degree of vanadium pollution in the analyzed waste dumpsites is in the following order, as shown in the pollution load index (VPLI) in Figure 2: Nekede dumpsite > Rice-mill dumpsite > Okpuno-Egbu dumpsite > Enyimba dumpsite. It can be seen that Enyimba, Okpuno-Egbu, and Rice-mill dumpsites experienced heavy pollution while Nekede dumpsite experienced extremely heavy vanadium pollution. Similarly, when compared to other investigations, higher values were observed [18, 22, 40–43]. In addition, Cao et al. [17] and Teng et al. [2] reported higher VPLI in surface soils within a mining and smelting area in China, and in top soils within an industrial area in China respectively.

3.4 Correlation analysis

Pearson's correlation coefficient was determined in the form of matrices and utilized as a measure of similarity and inter-relationship between vanadium contents in the selected waste dumpsite soils analyzed in this study (Table 3). The results revealed a strong and positive

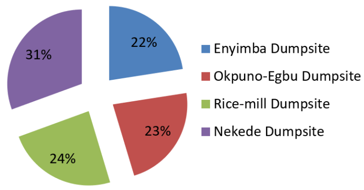

Figure 2 Pollution load index of vanadium in the studied waste dumpsites

correlation between Enyimba/Nnewi (r = 0.634), Nekede/Nnewi (r = 0.615), and Nekede/Rice-mill (r = 0.842) dumpsites. This implies that the metal (vanadium) found in the studied waste dumpsites are likely from the same origin (source). The source of the vanadium pollution in the studied waste dumpsite soils are anthropogenic activities such as disposal of domestic and industrial wastes containing iron and steel. It is worth noting that a strong and positive correlation (0.50 – 0.99) between two variables implies that an increasing in one causes the other to increase. Contrastingly, a strong and inverse/negative correlation between two variables implies that an increase in one variable causes the other variable to decrease [28, 29].

Table 3 Correlation matrix showing the degree of relationship between the studied waste dumpsites

	Enyimba Dumpsite	Nnewi Dumpsite	Rice-mill Dumpsite	Nekede Dumpsite
Enyimba Dumpsite	1			
Nnewi Dumpsite	0.633867	1		
Rice-mill Dumpsite	-0.00515	0.100432	1	
Nekede Dumpsite	0.394534	0.615219	0.842469	1

4 Conclusion

This research has revealed the pollution and ecological risk of vanadium in waste dumpsite soils in southeastern Nigeria. The background level for unpolluted soils was found to be exceeded in the dumpsite soils. The ecological risk implications of vanadium in these soils have also been identified. Although vanadium at lower concentrations in soils plays a significant role in plants, an increase in its concentration is often associated with adverse negative effects on photosynthesis, mineral nutrition, growth and development, plant-water relations, and grain yield due to bioaccumulation and uptake beyond an acceptable limit. Based on these findings, there is a dire need for remediation of waste dumpsite soils due to the associated negative impacts on health and the eco-system.

Availability of data and materials

All data and materials are available.

Competing interests

The authors declare that they have no competing interest.

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